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"On a Multiple Induction Machine for producing High Tension Electricity, and on some remarkable Results obtained with it." By LORD ARMSTRONG, C.B., F.R.S.

Received May 18,—Read June 16, 1892.

[PLATES 2—13.]

It is now nearly half a century since I undertook to design, for the Polytechnic Institution then existing in London, a large hydro-electric machine, on the plan of the smaller one I had previously designed for myself. It was a very short time in my hands after its completion, and I had scarcely any opportunity of afterwards using it in the lecture room of the Institution. My experience with it was, however, sufficient to show me that its great power was very much less when used in a room than in the outside atmosphere when dry. I have ever since entertained the idea of constructing a similar machine of equal or greater power for my private use; but, until lately, the exigencies of business pursuits precluded my giving attention to the subject.

On recommencing my experiments on this branch of electrical science, my immediate object was to improve the frictional apparatus of the steam jet, so as to obtain the greatest effect from a given expenditure of steam, while my ultimate intention was to construct a large machine with such a number of jets as would afford me a more copious supply of frictional electricity than could be obtained by any other convenient means. I soon found, however, that the difficulty of obtaining effectual insulation in the open air, except under the most favourable conditions of weather, would involve great interruption and disturbing effect, and I therefore turned my thoughts to the induction coil as a source of high tension electricity, that would not only be independent of the caprice of the weather, but would also save me from atmospheric inclemency, which, however harmless it might have been in the youthful days of my hydro-electric experiences, could not be safely endured at my present advanced period of life.

I did not flatter myself that I could make any important improvement upon the Ruhmkorff coil. That remarkable instrument had been so long in use, and had undergone so much development, that its career of progress might well be considered as nearly, if not quite, played out. But although Ruhmkorff coils had been constructed capable of yielding sparks of unprecedented length, yet it was obvious that the output of electric energy, when estimated in ampère as well as in volt measurement, must be relatively very inferior to that of smaller coils, in which each convolution of the

secondary wire is effected with much less length of wire. In other words, a given weight of material utilised in a number of small coils ought to yield a greater output of energy than the same weight used in the construction of one large coil, the best proportions of length to diameter being in each case adhered to. Moreover, it is well known that, with induction coils of exceptional magnitude, the ordinary vibrating contact breaker cannot be efficiently employed on account of the rapid destruction of the platinum points; and the method of obviating this difficulty by breaking contact under a cover of alcohol is only compatible with slow action. But by dividing the work amongst several coils, each with a separate vibrating contact breaker, this difficulty is avoided, and the frequency of the spark is multiplied in proportion to the number of coils and contact breakers. With these views, I obtained from Mr. Apps six induction coils, each capable of yielding a maximum spark of $10\frac{1}{4}$ inches. I had also a six-fold contact breaker constructed of the usual automatic vibrating type, and in which each vibrator was acted upon by an independent electro-magnet of the horse-shoe description. In experimenting with a single contact breaker used with a single coil, I found much advantage in augmenting the power of the working magnet, and in stiffening and shortening the spring greatly beyond the limits of ordinary practice. By so doing I was enabled to reduce the range of vibration, and thus to obtain with a heavy-headed vibrator many times the usual speed of oscillation without reducing the length of spark in nearly the same proportion. With an extremely high speed of interruption, I could obtain sparks 4 inches long in great profusion, though not with rapidity equal to the rate of vibration. To accomplish that degree of rapidity the sparking distance had to be reduced to about one-half; but, considering that a spark of 2 inches is supposed to represent nearly 95,000 volts when delivered between knobs, and would probably give two-thirds of that amount when delivered between points, I saw no sufficient inducement to strive after longer sparks, which can only be obtained by great sacrifice of frequency, involving a general reduction of ampèrage far exceeding the gain in voltage.

By using two coils in series with an alcohol contact breaker worked slowly, I could get sparks 15 inches long; but I found so many difficulties and inconveniences in a serial arrangement, and so little to be gained by it, that I abandoned the pursuit of it, and confined my attention to a combination in parallel. In the first instance I employed a secondary battery of seven large cells to supply the current for exciting my six coils, and I fully expected that their united output would be proportionate to their number, but in this I was disappointed. I found that two coils gave me only about one and a-half the effect of one, and that every additional coil gave a dimin-

ished increment of output. In fact, when all the six were in action, I only got about three times the output I obtained from one. It was some time before I discovered the cause of this apparent anomaly; but at last I traced it to the recoil currents from the condensers, which at each interruption of the primary current had to pass through the battery in the reverse direction of the battery current. Thus a conflict of currents was produced in the primary circuit, which checked the acquisition of magnetism by the coils. I saw no remedy for this interference, except the application of a separate battery to each coil, and I accordingly exchanged my single battery of seven large cells for six independent batteries composed of the same number of cells proportionately reduced in size, and when this was done I obtained the full measure of effect.

Side by side with the multiple contact breaker I have a mechanical contact breaker, in which the interruptions are effected by insulated cam wheels fixed on a revolving shaft, which is fitted with spur gear for high velocities. This mode of breaking contact has the advantage of causing the sparks to be delivered in regular sequence, with equal intervals between them. It also enables the exact number of discharges per second to be ascertained; but the automatic interruptor gives a larger output, owing, I suppose, to the fact that each break of contact takes place exactly at the moment when the magnetisation of the coil is matured, whereas with the mechanical break the same degree of coincidence cannot be attained. The six coils are placed vertically beneath an ebonite table, through which the connecting wires are conveyed in strong glass tubes, which also serve as pillars for supporting the sparking points. These points are adjustable for any required length of spark, and they operate in a radial direction against a metallic conductor surrounding an ebonite disc, which, by means of an india-rubber band and multiplying gear, can be very rapidly rotated; and, whether it be at rest or in motion, it serves as a collector, from which the united output of the coils can be drawn off. By rotating the wheel and conveying the current through a series of Geissler tubes fixed upon it in various positions, extremely brilliant symmetrical figures can be produced, but for all other purposes rotation is dispensed with, except to the extent of slight movements to regulate the length of spark without altering the adjustment of the points. A switch-board is provided for the purpose of regulating the number of coils to be thrown into action, so that they can be used singly or in any required number.

The power of this apparatus as indicated by the voltameter is much greater than that of the large hydro-electric machine made for the Polytechnic Institution, but it is very inferior to it in regard to length of spark, to which, however, I attach but little importance. I find it well adapted for experimental investigation, and I have obtained with

it some very interesting results. A drawing of it accompanies this paper (Plate 2).

My attention was at first directed to the heating effect of the secondary current at an air gap on its circuit. The amount of heat developed at this point when all the coils were in operation proved unexpectedly large, and I was surprised to find it almost entirely confined to the negative side of the gap. I found, also, that when the current passed in sparks very little heat was exhibited. It was only when the passage of the current assumed the appearance and condition of an arc that the heat came into prominence. Taking platinum wires of No. 27 B.W. gauge for the positive and negative terminals, which I shall call electrodes, to distinguish them from the sparking points at the collector, I found that the ends could be drawn asunder to a distance of fully an inch before a decided stream of crackling sparks was elicited, and even then the sparks presented a hazy appearance. On re-advancing the ends to each other the sparks diminished, while the haze increased and gradually assumed the condition of a pale blue arc. At a distance of 0·6 inch a well-defined arc could be maintained, though not without a slight admixture of faint sparks, which followed the curvature of the arc. At this distance the heat was sufficient to fuse the end of the platinum wire forming the negative electrode, but the heat did not reach its maximum until the separating distance was reduced to a few hundredths of an inch. At that small distance the negative platinum melted with great rapidity, and ran back in a globule until it got out of melting range of the arc. By following up the melted globule by steadily advancing the positive wire, the negative wire fused at the rate of nearly 3 inches per minute; but, however long this process was continued, the positive wire remained to all appearance perfectly cool. Retaining the positive wire unaltered, I increased by successive steps the thickness of the negative wire, to determine the point at which it became too thick to melt and run back in a globule, and it was not until I increased the thickness up to 16 gauge, which corresponds to a diameter of 0·065 inch, that I reached this limit. With that wire the end melted into a rounded form, but no longer receded in a gathering globule, as thinner wires did. Iridioplatinum wire of 21 gauge, containing 70 per cent. of iridium, readily melted and receded, though not rapidly, until the globule fell by its weight. In this instance the light emitted from the globule was so intolerably bright as to require darkened spectacles to view it with impunity. I next proceeded to ascertain how far it was necessary to reduce the thickness of the positive wire before it exhibited an equal degree of heat with the thickest wire opposed to it on the negative side, and I found that I had to diminish its diameter to 31 gauge before this equality was reached. Now, the sectional area of No. 16 gauge is 42 times

the area of No. 31 gauge, and from these figures an estimate may be formed of the difference in the development of heat on the negative and positive sides. When I employed two carbon electrodes of equal thickness the greater development of heat on the negative side was still very decided, though the difference was not so conspicuous as in the case of the platinum electrodes. In the arc lamp the superiority of heat is largely on the positive carbon, and it is difficult to account for the contrary result obtained in my experiments.

I further varied these experiments by taking the positive discharge from the surface of acidulated water, in which case the negative electrode was melted by the arc flame springing from the water. I also used for the positive electrode a lump of ice sprinkled with salt to make it conduct, and obtained the same result. A reversal of the current made the water boil at the surface and melted a hole in the ice, while the positive platinum remained unheated as usual. In another experiment I enclosed the two platinum electrodes in glass tubes sealed at the outer end, leaving about $\frac{1}{8}$ inch of the platinum wire (No. 27) projecting beyond the glass. These sealed ends I immersed in distilled water, and succeeded in melting the exposed portion of the negative wire while submerged in the water.

In another case I used an iron wire (No. 20 gauge) on the negative side, retaining the platinum wire for the positive electrode. In this instance the melted globule ran back very quickly to a distance of about $\frac{1}{2}$ inch, then stopped and burst into intensely brilliant flame, which showed a strong disposition to cross over to the opposite side, but appeared to be beaten back by the blue flame of the arc. Part, however, did reach the positive electrode, and condensed upon it in the state of an oxide. My attention having been thus directed to an appearance of conflict in the arc, I discarded the iron wire and substituted a platinum wire dipped in a brine of common salt, so as to impart a distinguishing yellow colour to any flame that might issue from the negative side in opposition to the flame emanating from the positive side. This caused the arc to be exhibited under two colours —a very decided yellow on the negative side, and the same pale hazy blue as before on the positive side, but the yellow flame was beaten back by the blue flame. Flecks of yellow could, however, be seen to get across occasionally. It was not so easy to produce yellow flame from the positive electrode, because there was not sufficient heat in the positive wire to volatilise the salt; but by using a separate wire encrusted with salt, and holding it alternately immediately in front of each electrode, I could produce yellow flame on either side and observe the difference of its behaviour in the two cases. When held on the positive side a dense unbroken stream of yellow flame supplanted the previous blue, and passed over bodily to the opposite wire; but when held on the negative side the yellow flame struggled

with comparative feebleness to cross over, and only reached the positive wire in scanty fragmentary portions. These appearances were strongly suggestive of a dominating force emanating from the positive side and opposed by a weaker force of the same nature in the opposite direction. The oscillations which are known to attend every disruptive discharge necessarily involve passages from the negative as well as the positive side. In fact the spark must be regarded as consisting of a dying out alternating current of prodigious frequency in which the positive alternations have the ascendency over the so-called negative ones; the excess constituting the available current.

Although the arc flame presented no appearance of flowing motion, I thought it necessary to test the question of any movement in the longitudinal direction by bringing the arc in contact with light powdered substances. For this purpose I placed a small heap of chalk dust upon a plate of mica, and caused the arc flame to pass through it, but none of the dust was moved lengthways. The displacement was entirely lateral, the material being neatly heaped up on each side in a ridge, which curved inwards towards the points of the electrodes, beyond which no displacement was visible. The action appeared to be that of a gentle push, rather than that of a sudden impulse; but when sparks passed instead of flame, a scattering force was exerted, which operated sideways, and not in the track of the spark. In this case I observed that the scattered dust showed a tendency to settle upon the plate in curved lines and symmetrical figures. I followed up this hint by sifting fine black dust upon white cardboard and passing sparks over the surface, and I thus obtained most unmistakable proof of symmetrical arrangement. This, however, was only a crude method of procedure, and it required a great deal of perseverance and innumerable trials before I succeeded in producing the effect in a satisfactory manner. At length, however, I was enabled to produce perfect dust figures which presented pictures of the disruptive discharge revealing the existence of forces of which the eye could otherwise take no cognizance. Many of these figures I got photographed on the spot, and a selection of them accompanies this paper. They represent the effect not of a single discharge but of a succession of sparks, generally beginning with a light one and gradually increasing the power as the dispersion progressed. To put all the power into one discharge had too much dispersive effect and produced great irregularity in the figure. A perfectly even sifting of the dust was also essential to a good result, and this could only be effected by the entire exclusion of air draughts and a regulated action of the sieve. The best kind of dust to be used and its proper degree of fineness were also matters requiring many experiments to determine. The dust which I ultimately used consisted of calcined magnesia worked up in a mortar with a suffi-

cient quantity of pure carbon to give a dark slate colour to the combined mass. The carbon was in the form of an impalpable powder, and, I believe, consisted of purified lamp black. I tried every variety of discharge I could think of—sometimes weak and sometimes strong—sometimes from a single coil and sometimes from several in combination. The most powerful sparks were obtained by using all the six coils in parallel and discharging them simultaneously by the action of a single alcoholic contact breaker common to the whole. I also used a Leyden battery, consisting of four ½-gallon jars, which I joined up in various ways both in parallel and in series, and in some cases introduced a wet string to soften the discharge.

The circular lines which surround the main discharge, both horizontally and transversely, first demand attention. They appear to represent sections of concentric layers or shells, of which the spark is the nucleus. Their great similitude to the lines of force represented by iron filings under the influence of a magnet is suggestive of similar causation, but I could not find any proof of their identity. The distance to which this circular action extended was far beyond the limit exhibited by the photographs. By laying patches of extremely light dust on paper at various outside distances, I distinctly traced these lines at a distance of 18 inches from the centre of dispersion, and there can be little question of the action existing in a lessened degree at a still greater distance. It can hardly be doubted that the particles of dust are linked together by polar attraction, and they probably represent similar conditions of the air jerked out by the discharge, but whether it be possible to regard them as indications of tracks of diffused discharge of a different character from that of disruption is more than I dare venture to say. I am satisfied that they are not mere ripples resulting from pulsatory vibrations of air, for I find that radial pulsations produced by mechanical means merely clear a circle without the least tendency to form similar rings. I made the experiment by stretching a membrane over a tin cylindrical box, with a small air tube leading from the bottom to near the surface of a dusted card. The membrane was then set in motion by a rapid succession of light taps, which dispersed the dust in the same manner as the spark did, but not the least indication of circular lines could be seen, and yet air puffs play an important part in the process, for the effects are greatly modified by screens, as will presently appear.

The figures also show in the most unmistakable manner that the wires, as well as the spark, exercise a dispersive force. I am inclined to think that the dispersive action of the wire differs only in degree from that of the spark. We see in the lines emanating from the wires evidence of a molecular disturbance in the material which shoots off the molecules of air in contact with the wire. When the

action is very strong, as it is near the sparking terminals, the external molecules of the metal are themselves shot off, as is evident from the fact that the positive wire becomes reduced to a neck a little in rear of the sparking end when subjected to a prolonged succession of Leyden battery discharges. It is also well known that if a discharge from a powerful Leyden battery is sent through a very fine wire, the whole wire is exploded. Under ordinary conditions the cohesion of the molecules restrains their movement within very narrow limits, and confines their action to mere impulse on the surrounding air. Now, it appears to me that we may regard the track of the spark as a line of conducting air, which, having no cohesion to keep its molecules together, is exploded at every discharge, and, consequently, produces a far greater amount of dispersion than the wire. The force* of the lateral discharge at short distance is very great. In all cases the dust beneath the conducting wires was struck into the card, so as to leave a permanent delineation of the wire. The dust also over all parts of the figure, where the action was strong, was forced into the card, so as to leave a stain after the loose dust was shaken off, and thus a stained picture of remarkable accuracy, embracing the greater part of the figure, was in some cases preserved.

In all the figures the emanations from the positive and negative wires are of the same character, but present a great superiority of power on the positive side. This superiority is, however, much greater in the case of coil discharges than in battery discharges. This may be attributed to the oscillations between the inside and outside coatings of the Leyden jars suffering far less degradation than those between the terminals of the coils. If there were no degradation, the forces exerted on the positive and negative side would be equal and everlasting. The application of wet string to the battery lessens the difference between these opposite forces, but it augments the lateral displacement of dust from both wires while it diminishes the explosive force of the spark.

Diagrams of the dust figures are annexed (Plates 2—13), but, though admirably drawn, they necessarily fall short of the photographs in showing the delicate lines and shadings of the actual figures. To suit the pages of the 'Proceedings,' the diagrams are reduced to about half the size of the originals, but the exact scale is marked on each. The following is a descriptive list of the figures:—

No. 1 was produced by a succession of sparks from six combined coils discharged simultaneously. The tracks of the sparks, the surrounding circular lines, the impress of the positive and negative

* In one case I knocked a large piece out of the bottom of a thick glass trough, containing only an inch depth of water, by discharging an under-water spark along the bottom.

wires, the strong emanations from the positive wire and the feeble ones from the negative, are shown in this figure, as well as in most of those which are to follow.

No. 2 may be regarded as a transverse section of No. 1, being produced by similar sparks delivered vertically through a hole in the dust plate when fixed horizontally midway between the sparking points. It shows that the discharge is surrounded by circular lines in the transverse as well as in the longitudinal direction.

No. 3 is a similar transverse section taken a little in front of the positive point.

No. 4 is the same thing taken immediately in front of the negative point.

No. 5 is taken transversely immediately behind the positive point, and shows the radiations issuing from that part of the wire.

No. 5A shows similar radiations from the positive wire at a distance of about 12 feet in rear of the sparking point.

No. 6 was produced by a succession of discharges from four ½-gallon Leyden jars joined up in pairs, two in parallel and two in series. It will be observed that the circular lines are much more strongly developed than in the preceding figures, but that the radiations from the wires are less so.

No. 7 was produced in the same manner, and shows the circular lines still more highly developed.

No. 8 is the transverse section of No. 7 taken in the same manner as No. 2.

No. 9 is the same as No. 7, except that the conducting wires are brought down upon the card at a steep angle.

No. 10 was produced with battery discharges in the same manner as No. 6, but with a short wet string introduced to soften the discharge. This had the effect of greatly increasing the radiations both from the positive and negative wires, while it reduced the development of the circular lines.

No. 11 was produced under the same conditions as in the preceding case, except that the wet string was considerably lengthened.

No. 12 was similarly produced, but with a still further increase in the length of the wet string.

No. 13 was produced without any visible discharge across the dust plate. The same battery was used as in the last and several preceding cases, but the Leyden jars were allowed to leak sufficiently to prevent their reaching the sparking point. The same effect may be produced by taking the discharge at a by-pass with a shorter sparking gap than that on the dust plate.

No. 14. In this case the battery was discarded and sparks only from the combined coils were used, the same as in No. 1. It shows the effect of splitting the positive current by the use of a double wire

re-united at the sparking point. The double wire is bent into opposing bends and angles to show the repellent action of the radial emanations from the wires. The resting places of the dust are very beautifully shown by the darkened spaces in this figure.

No. 15 was produced in the same manner as the preceding, but on glass instead of card. As the dust is so very easily moved on glass, only one coil was used, and it is remarkable that the dispersive effect exhibited by the double positive wires is actually greater than that of the spark itself. It will be seen that the dark impress of the wire is more marked upon the glass than upon the card. It will be observed also that there is a very peculiar dark band lying outside of each wire and running parallel with it, and that each of these bands merges in a dark patch lying on each side of the sparking point. These bands and patches may be assumed to represent places where the dispersive force is considerably subdued.

No. 16 is a transverse section of battery discharges showing the deflections of the circular lines produced by the interference of six glass tubes $2\frac{1}{2}$ inches long and $\frac{5}{8}$ inch in diameter, erected on the dust plate at equal distances from the centre and from each other. It will be observed that the lines are not obliterated behind the tubes and that curious new curves are developed.

No. 17 shows similar effects produced by heavier discharges on a more thickly covered dust plate. In this case it will be seen that the circular outline of the figure is changed by the operation from a circular to a twelve-sided form. A blunted angle is thrown out opposite each glass tube and another midway between every two.

No. 18 shows another dust plate similarly treated, but more lightly covered and without the glass tubes, instead of which two flat screens of cardboard, 3 inches high and 2 inches wide, were fixed perpendicularly on opposite sides of the centre. In this case, although the lines curve inwards behind the screens, they gradually die out towards the centre and leave the middle portion undisturbed, but by reducing the height of the screens to the level of the sparking point the whole sheltered space became wholly filled up with lines as in the two previous cases.

No. 19 shows the effect of inverting two wine glasses upon the dust plate so as to cover two circular patches of the dust and protect them from the action of the air. In this case no lines were found within the glasses.

No. 20 shows a stained figure remaining on the card after the dust was shaken off. Although there are some small portions where the stain has failed to take effect, the figure is, upon the whole, preserved with remarkable accuracy.

No. 21 is another example of a stained figure in which some of the circular lines are discernible.

[No. 22 shows a circular barrier of six wooden hemispheres, each $1\frac{1}{2}$ inches diameter, and touching one another, formed round the centre of the dust plate, and the dust was swept off the inner space before making the experiment. The positive sparking point was level with the top of the hemispheres, and the discharges were delivered from a Leyden battery of two $\frac{1}{2}$-gallon jars in series. It will be seen that the whole of the dust outside the barrier is thrown into lines which form arches over each touching point of the hemispheres, and that the spandrils are filled up with inverted curves. Although it is not easy to see how these arches and curves can be attributed to eddies, yet appearances favour the view that the lines are due to the combined effect of obstructed air drift and electric polarity. A barrier formed by a continuous perpendicular screen of the same height as the hemispheres almost entirely prevents the formation of lines.—*June* 9.]

Reverting to the subject of the development of heat at the negative side of the arc, the question arises, from what source is the heat derived? It cannot be acquired by conduction from the flame, for mere conduction would heat both wires alike, nor can it be the result of convection, for the arc is stagnant in the longitudinal direction. The only explanation I can see is that the negative wire requires time to take up the sudden gushes of current that come over from the opposite side, and which, not being instantly carried onward, produce a tumultuous agitation of molecules at the receiving end of the wire, resulting in the manifestation of heat. The thicker the wire the greater the facility of passing on the current, and hence less heat is evolved in a thick than in a thin wire. On the other hand, the positive wire receives comparatively small returns, and therefore a relatively thin wire suffices to pass on the pulsations without its being heated to ignition. But the question remains, why is it that so much less heat is produced by the spark discharge than by the arc discharge? Probably the chief reason is that the spark represents less quantity of current, though higher in potential. Another reason may be that the spark expends more energy in mechanical disturbance than the arc. Then, again, there is the question, what is the relation between the spark and the arc? I cannot find that the spark is possessed of mechanical impulse in the direction of its length any more than the arc. Both produce lateral but not longitudinal dispersion. I have discharged a quick succession of powerful sparks in a downward direction so as to pierce a piece of thick cardboard suspended from a delicate balance-beam, but without effecting any decided disturbance of the balance. Every spark left a burr on each side of the card apparently equal in size, which alone is sufficient to show that the spark does not pierce like a needle. Probably the arc and the spark are of much the same nature, the spark

being a single act of discharge and the arc a multitudinous succession of minutely divided sparks, of which none are sufficiently strong to produce any violent disturbance of the adjacent air. The hissing sound emitted by the arc seems to favour this view.

I now come to another set of experiments, which will only require a brief notice. They were designed to show the effect of passing both the arc and the spark through an intervening combustion flame.

Speaking generally, the intervention of flame has much the same effect in increasing the length of the disruptive discharge, whether in the shape of arc or spark, that is effected by rarefaction of air; but I will here only particularise some curious effects I obtained with the flame of paraffin candles. The annexed series of illustrations exhibit the effects observed in each case.

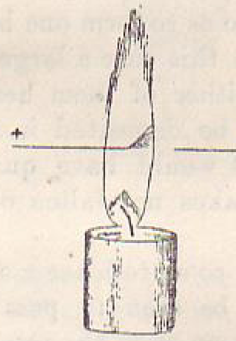


Fig. 1.

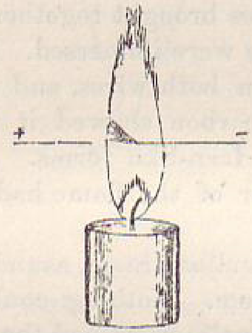


Fig. 2.

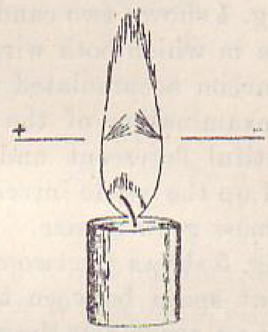


Fig. 3

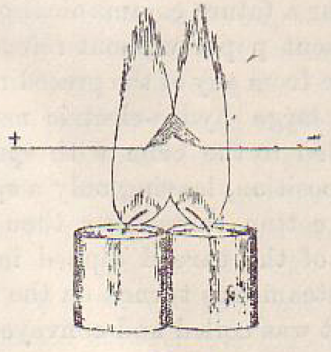


Fig. 4.

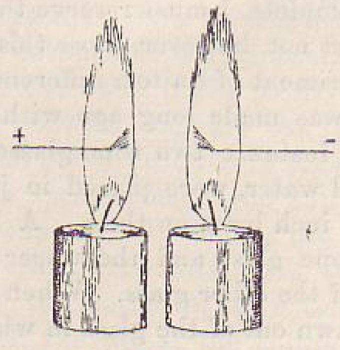


Fig. 5.

Fig. 1 shows the positive wire immersed in the flame and the negative wire clear of it, both wires being of platinum and of 22

gauge. A brilliant jet of pale-yellow flame was projected from the positive wire as shown, but did not go beyond the candle flame. Nothing was to be seen in the interval between the flame and the negative wire, which, nevertheless, heated as usual. It is quite possible, however, that there might be an arc communication rendered invisible by the intense brilliancy of the jet within the candle.

Fig. 2 shows the negative wire immersed in the flame and the positive clear of it. Here the direction of the jet was reversed, and the negative wire, instead of heating, became covered with a clot of carbon; but with a thinner wire the negative did heat, and no clot of carbon was formed.

Fig. 3 shows the effect when both wires were clear of the flame. In this case two jets of brilliant light appeared in the flame with a slight separation and an appearance of conflict between them.

Fig. 4 shows two candles brought together so as to form one broad flame in which both wires were immersed. In this case a large clot of carbon accumulated on both wires, and neither of them heated. An examination of the carbon showed it to be deposited in very beautiful florescent and fern-like forms. It would have quickly filled up the whole interior of the flame had flakes not fallen off as the mass grew in size.

Fig. 5 shows the two candles drawn asunder so as to leave a small vacant space between them. Nothing could be seen to pass this dividing space, but the results remained the same as in the previous case.

The repellent action which is exhibited in all these cases is not easy to explain, seeing that the discharge on both sides seems bounded by the exterior of the candle flame.

I am at present continuing my experiments, but under the altered conditions of discharge in rarefied air. As these experiments are far from complete, I must reserve them for a future communication.

I must not, however, close this present paper without referring to an experiment of quite a different type from any of the preceding, and which was made long ago with my large hydro-electric machine. In that instance two wine glasses, filled to the brim with specially-distilled water, were placed in juxtaposition, leaving only a space of about $\frac{1}{4}$ inch between them. A long cotton thread was then coiled up in one glass and the upper end of the thread dipped into the water of the other glass. When the steam was turned on the thread was drawn out of the glass in which it was coiled and conveyed with great rapidity into the other glass, and for a few moments a rope of water remained suspended between the lips of the two glasses. It was only when the machine was at its maximum power that I could do this, and it never reached its highest power when used within the

London building; but with my multiple machine I have succeeded in reproducing the experiment in a modified form. Taking two glasses of the form shown in fig. 6, placed near to each other as in the original experiment, I inserted in one of them a block tin cup in the manner shown in the figure. Into this cup I coiled a string composed

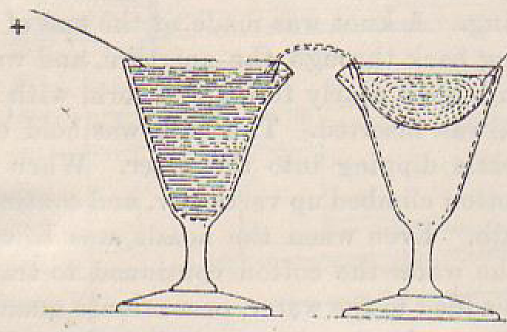


Fig 6.

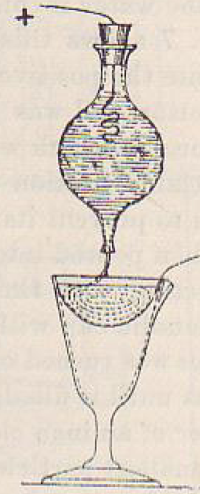


Fig. 7.

of ten strands of fine lamp cotton, which, when laid together, were of a sufficient section to make an easy fit for a hole of $\frac{1}{8}$ inch in diameter. The negative wire was put in contact with the tin cup and the positive wire was inserted in the other glass. The upper end of the cotton string was then laid over the edges of the two glasses, and the tin cup and the positive glass were then each filled with chemically pure water up to the same level. When the current was turned on the cotton string commenced to crawl over the edges of the two glasses, and never ceased to travel until it was bodily transferred from the negative cup into the positive glass. It was natural to expect that the water with which the cotton was loaded would travel with the cotton and raise the level of the water in the positive glass above the level of that in the tin cup, but the contrary was the case. The water lowered in the positive glass and overflowed in the tin cup, the surplus descending into the empty space beneath the cup, where its quantity could be seen and estimated. In short, the cotton travelled one way and the water the other, notwithstanding that the flow of the water was in opposition to the motion of the cotton. No spark passed between the glasses until the tail of the cotton ceased to touch the water in the cup, and then sparks passed in profusion. When the cotton was restrained from travelling, the water came over from the positive side in greater abundance, but when the cotton was dispensed with, and the gap between the vessels was bridged by a

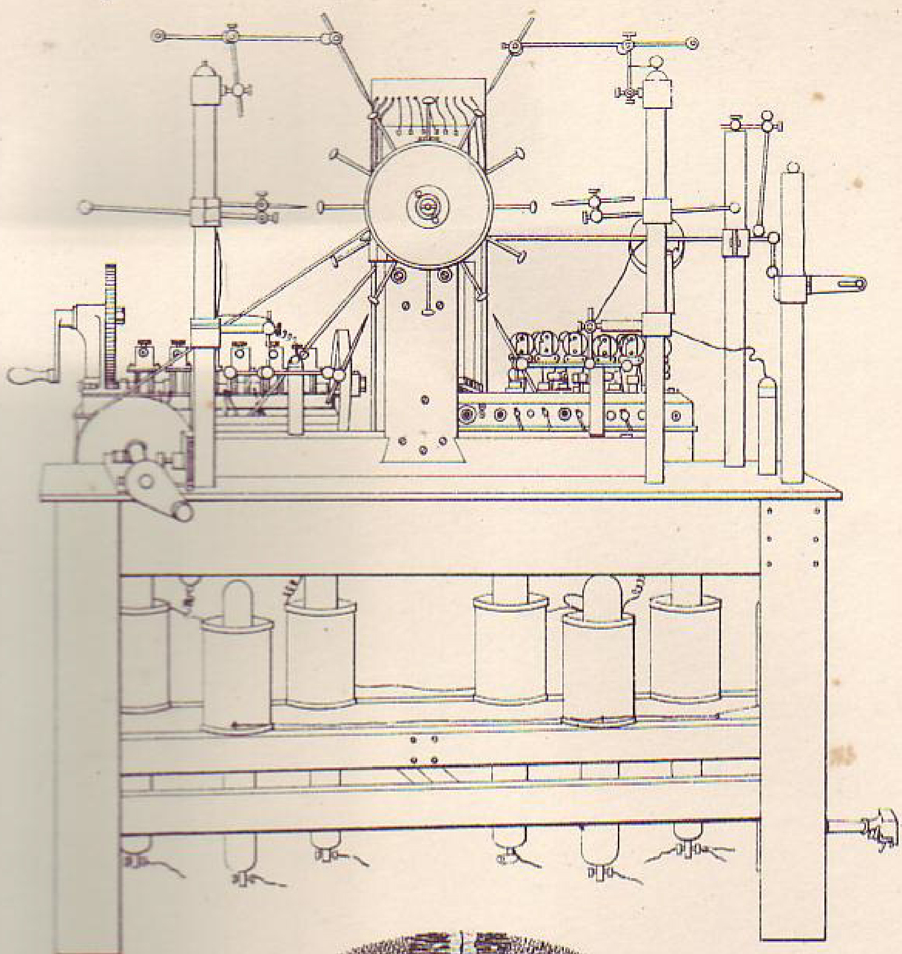
siphon glass tube, the water entirely ceased to pass. I am therefore led to believe that the intervention of capillarity is essential to the production of the effect.

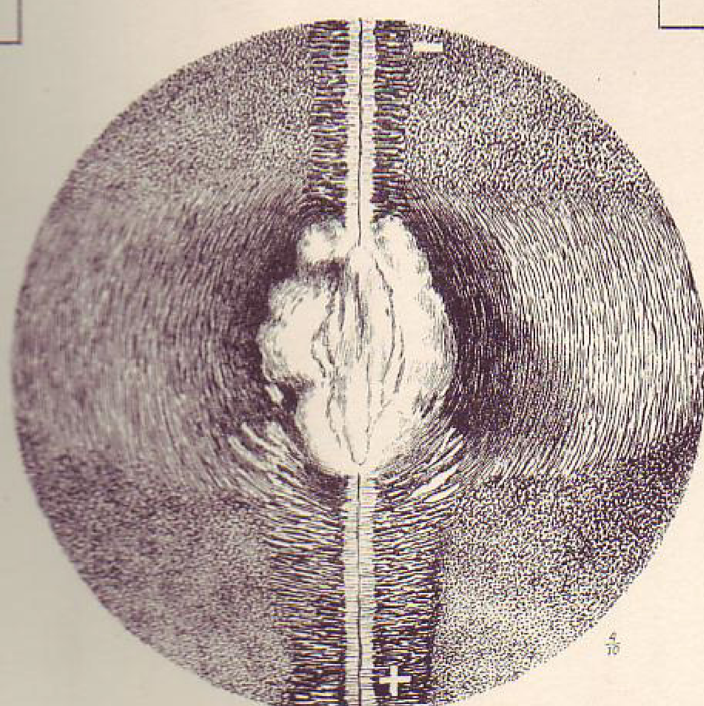
The tin cup is not essential to this experiment, and was merely used to afford a separate lodgment for the water brought over from the opposite side, and at the same time make the best possible contact with the water it contained.

Fig. 7 shows this experiment in a still more striking form. In this case the positive glass was dispensed with, and the upper end of the cotton coil was passed into a glass bulb through a nozzle, the aperture in which was just sufficient for the cotton to fill without appreciable friction in moving. A knot was made at the end of the cotton to prevent its dropping back through the aperture, and water was then poured into the bulb until nearly full, and a cork, with the conducting wire through it, was inserted. The bulb was held over the metallic cup with the nozzle dipping into the water. When the current was turned on the cotton climbed up vertically, and continued to pass until it filled the bulb. Even when the nozzle was lifted a quarter of an inch clear of the water the cotton continued to travel. The smallest particle of salt added to the water, or a minute quantity of anything that increased its conducting power, destroyed the effect and caused gas to appear at the electrodes.

The only experiment that I know of that presents any analogy to the effect thus obtained is that which appears to depend upon what is called electrical endosmose, in which case a porous diaphragm has the power of transmitting water from a cell containing a positive electrode into an adjoining one containing a negative electrode. If we may assume the capillarity of the cotton to represent the porosity of the diaphragm, it is reasonable to suppose it capable of transporting the water. Then as to the cotton travelling in the reverse direction, that may possibly be due to the reaction attending the transmission of the fluid. At all events it would appear that capillarity is controllable by electricity, and the question arises, what is the relationship between the one and the other?

The difference in the action of the current in this experiment and in that which I made with the hydro-electric machine consists in this:—That in the early experiment one thin cotton thread was moved with a high velocity, while in the latter experiment a mass of cotton equal to more than 100 similar threads was moved with a low velocity. This difference is probably due to the current being continuous in the one case and pulsatory in the other, also to its being of higher potential and smaller volume in the hydro-electric than in the multiple machine. When I attempted to use a single fine thread with my present machine the water upon it immediately boiled, and the thread was destroyed by sparks.





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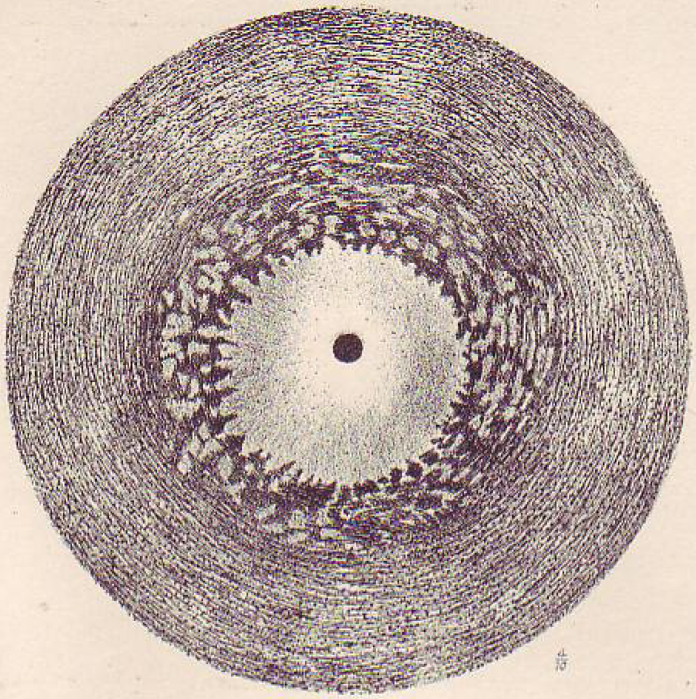

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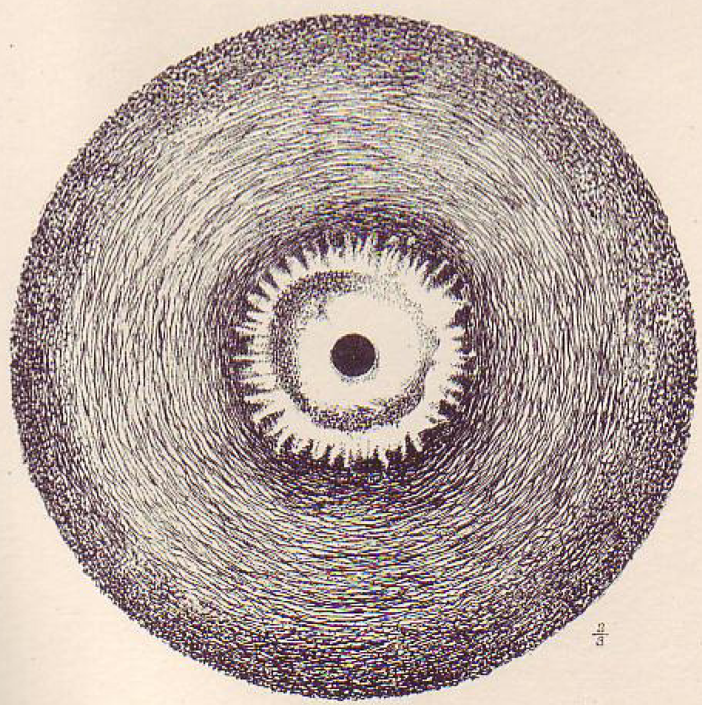

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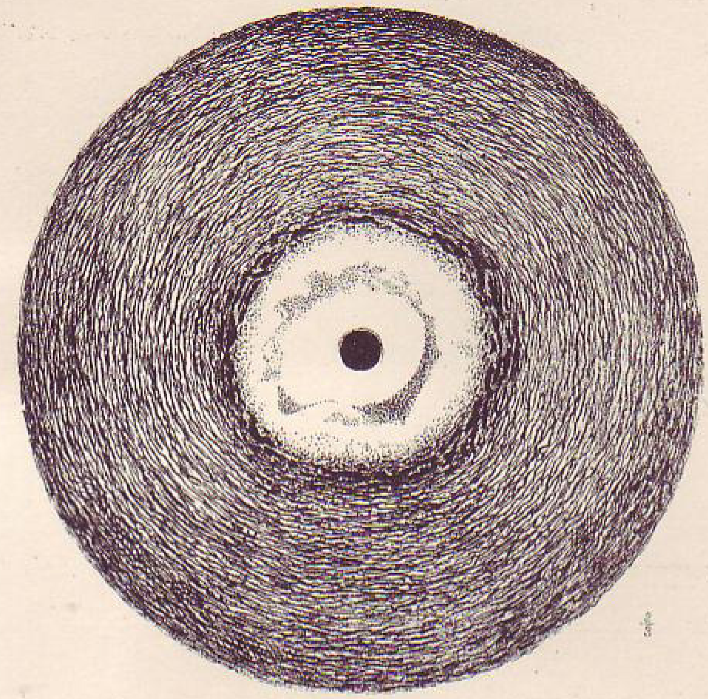

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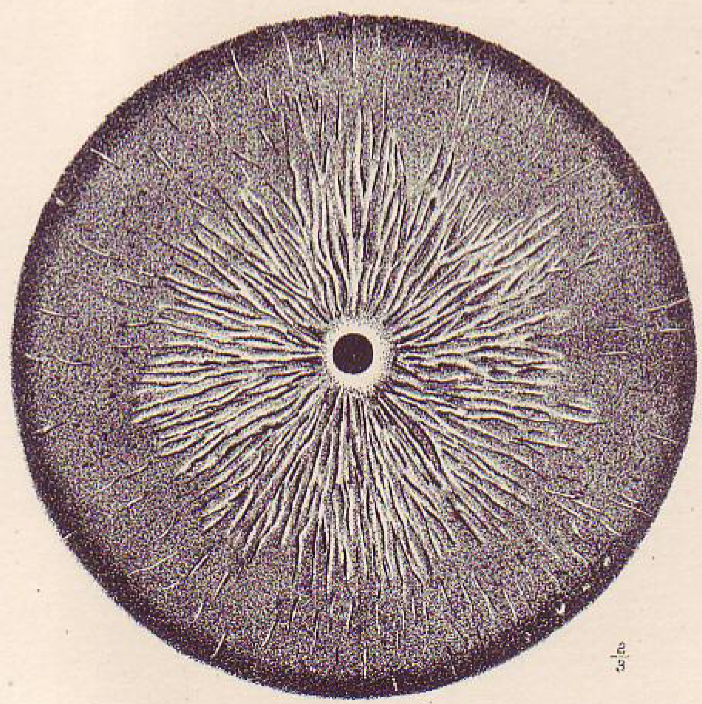

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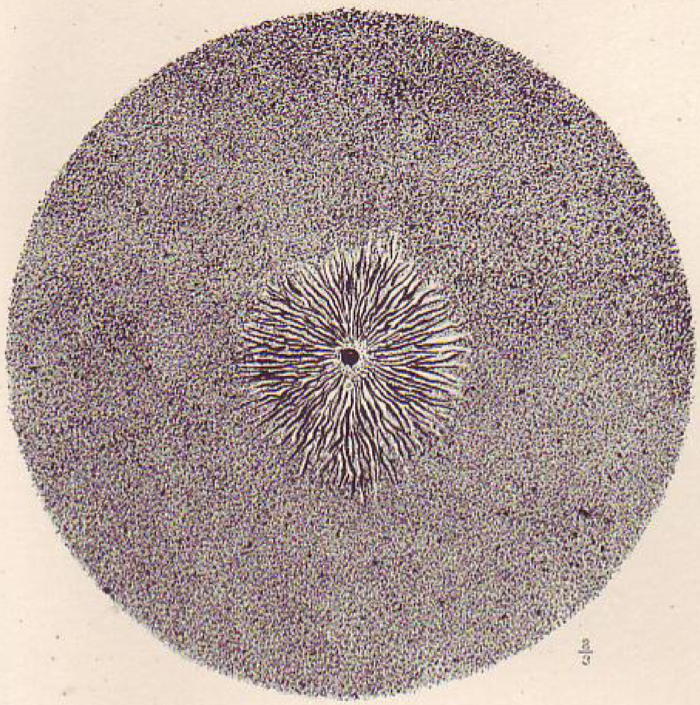

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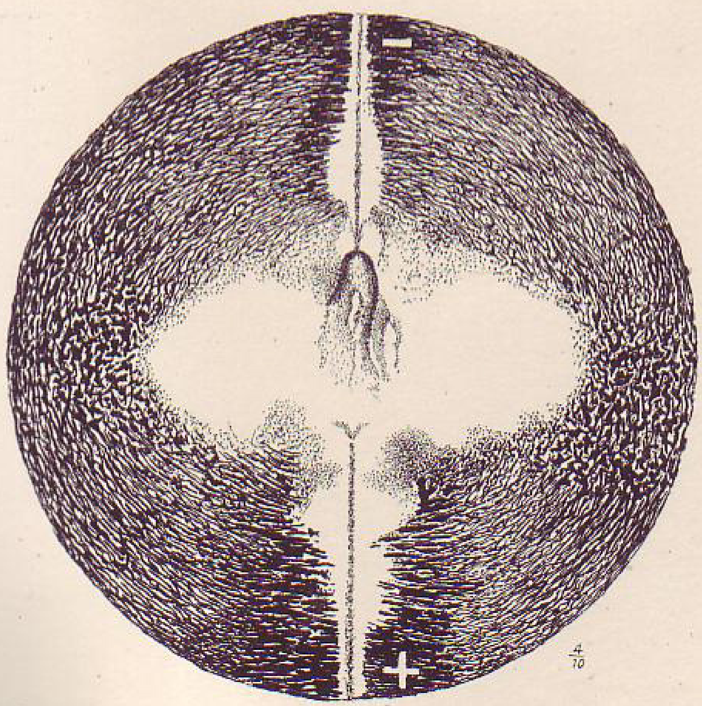

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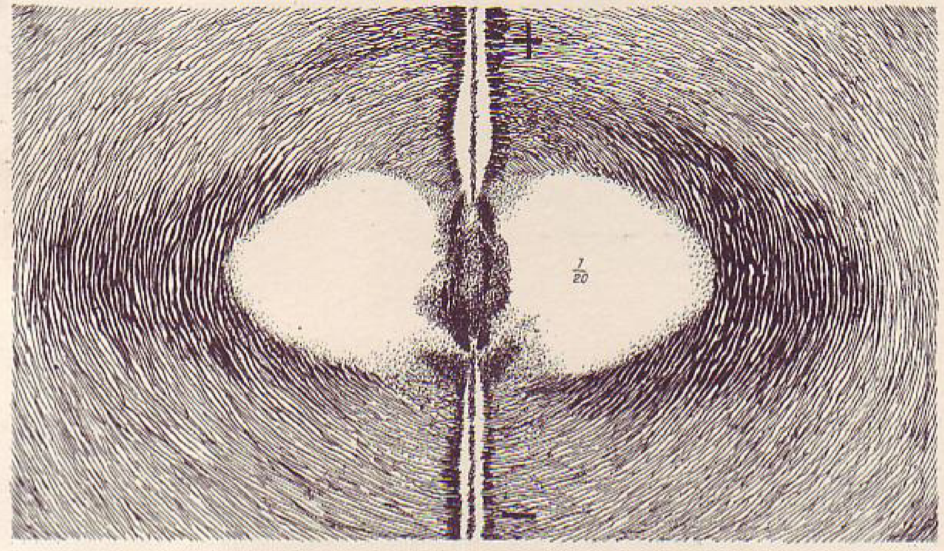

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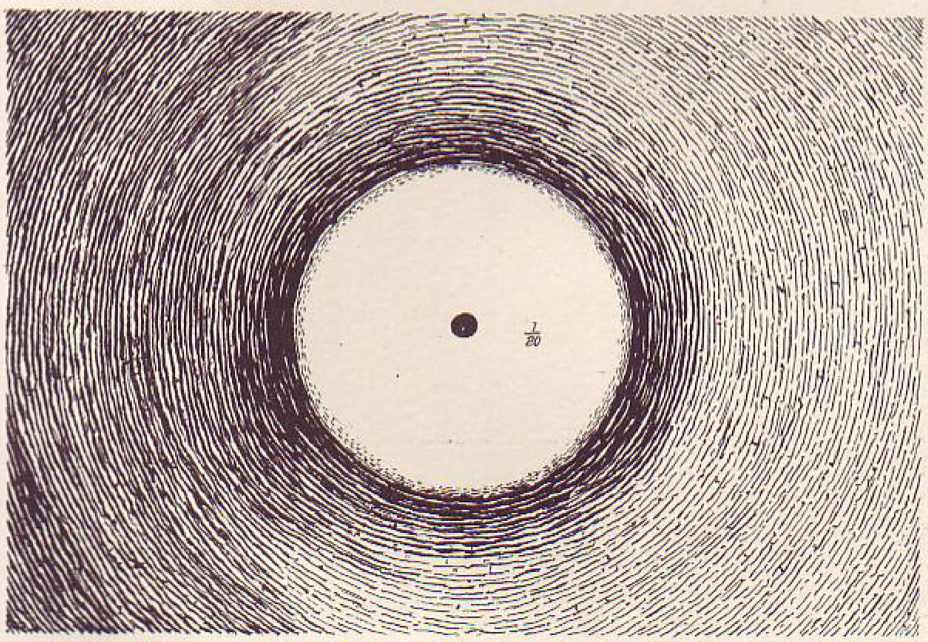

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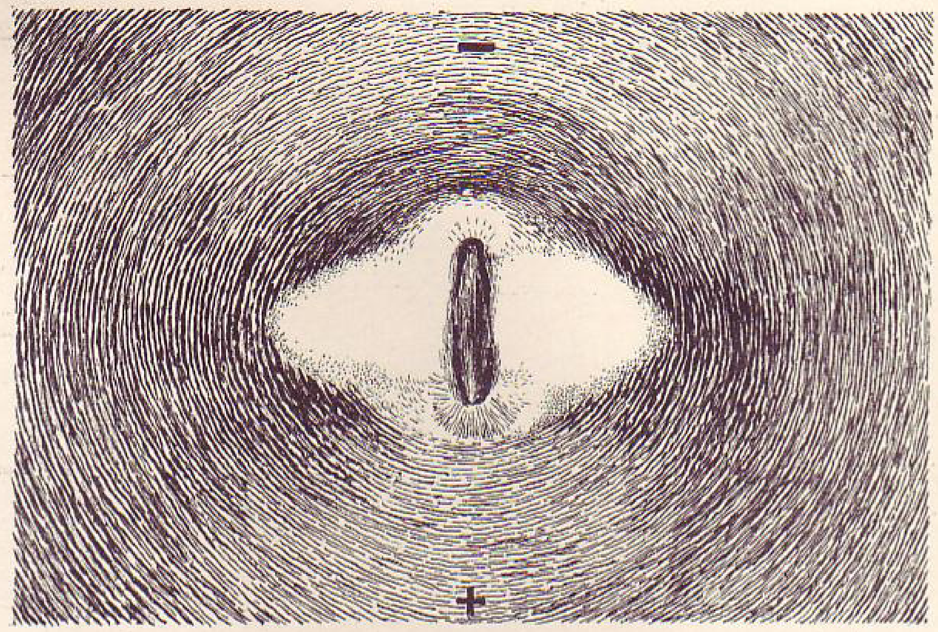

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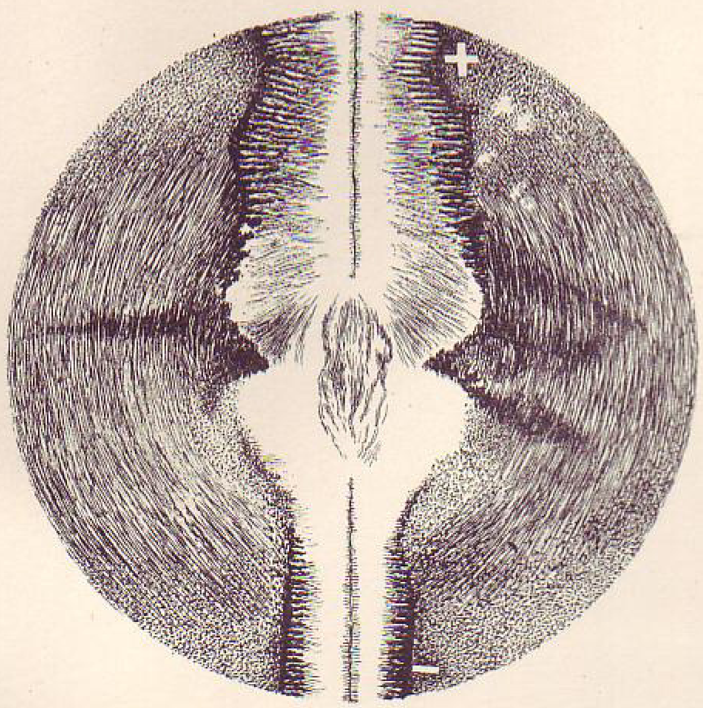

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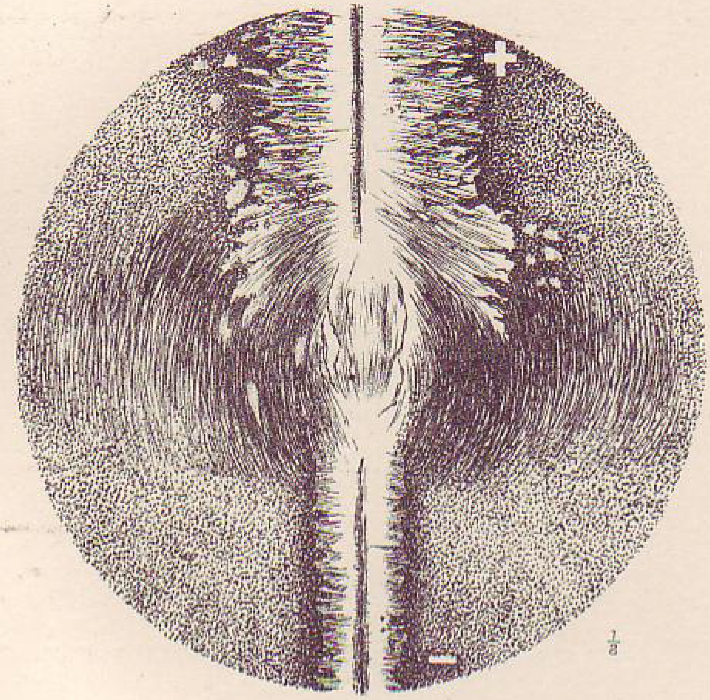

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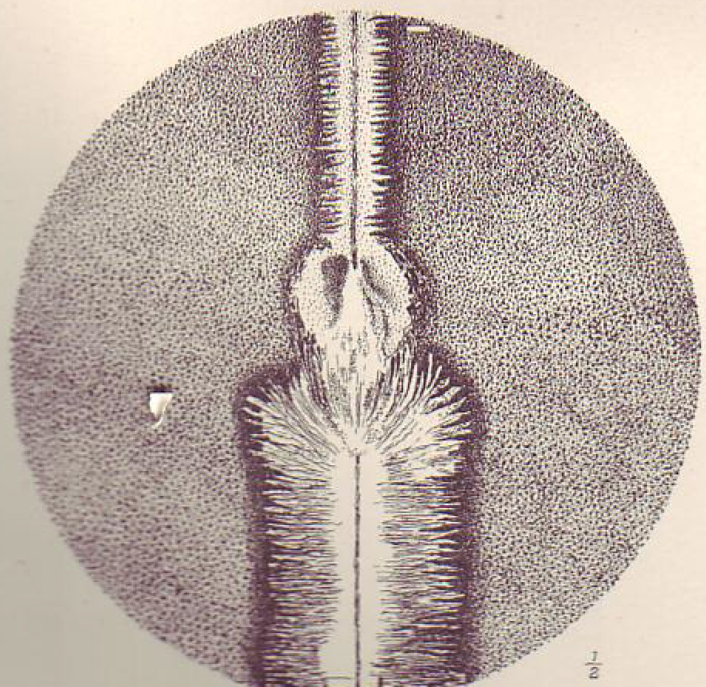

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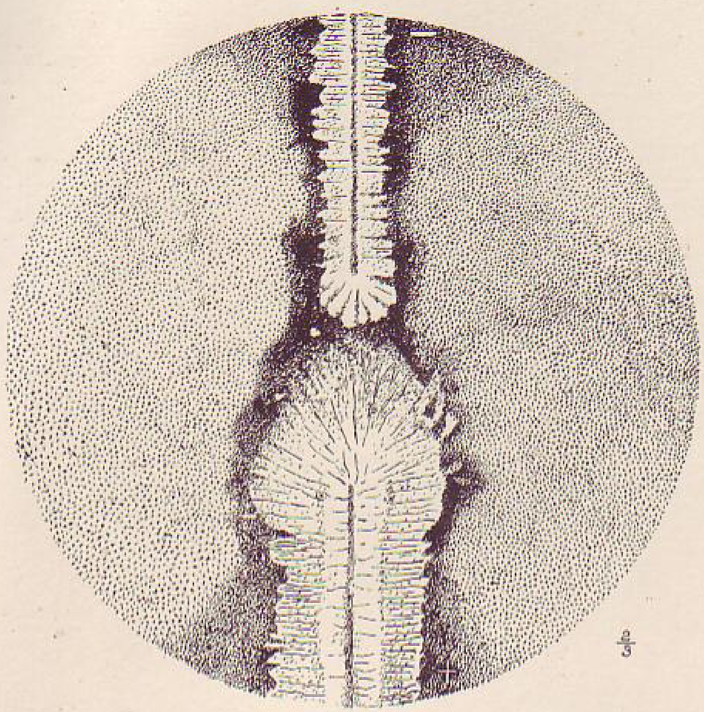

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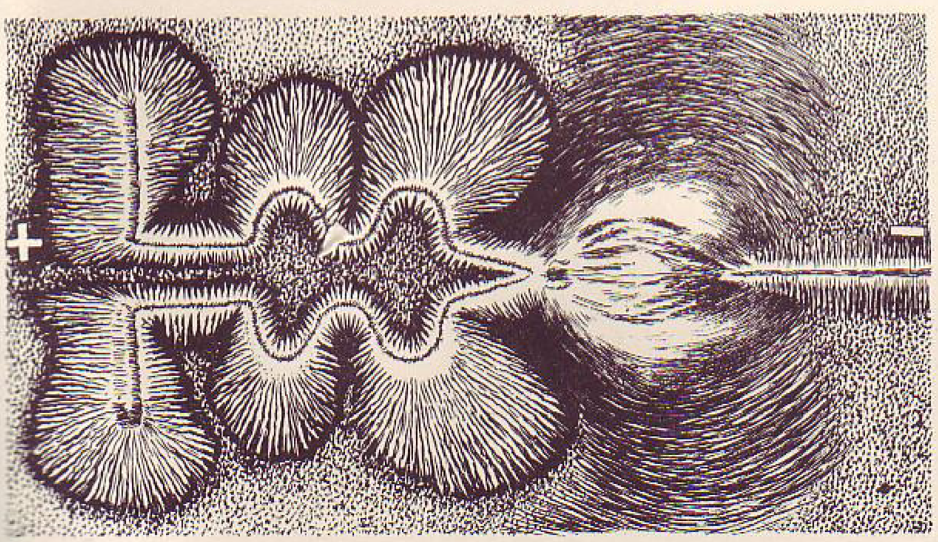

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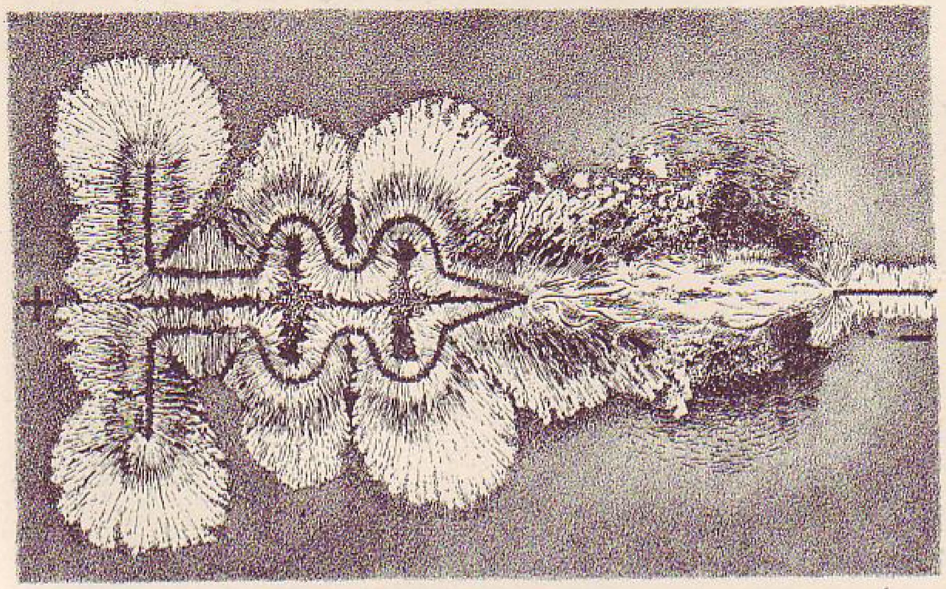

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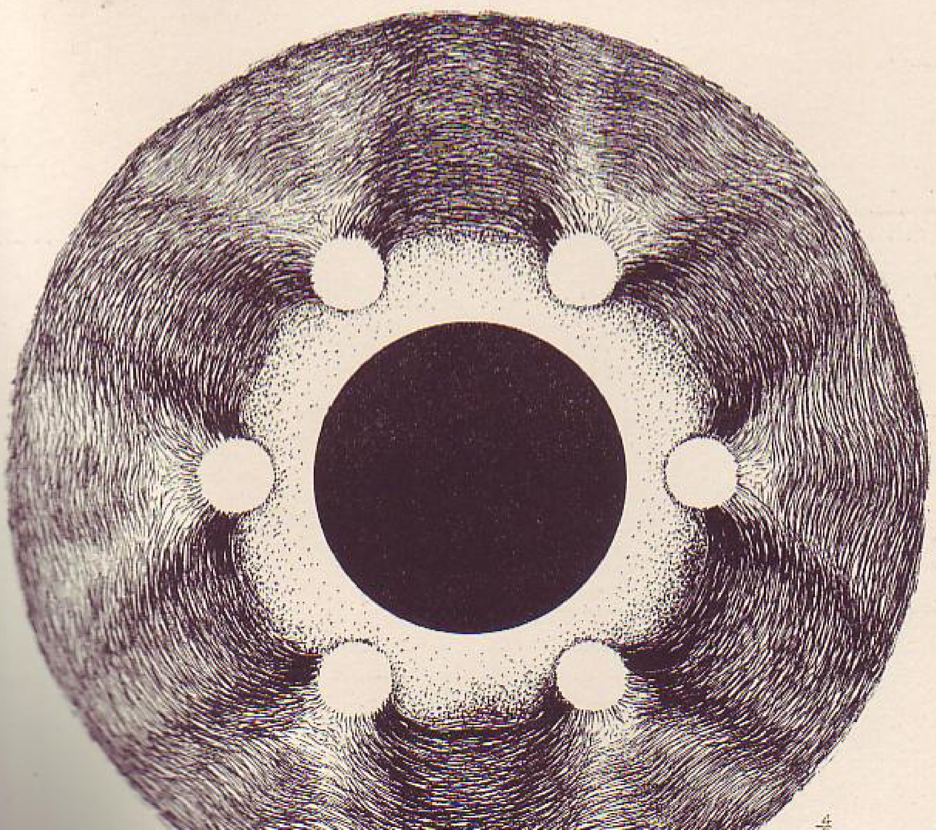

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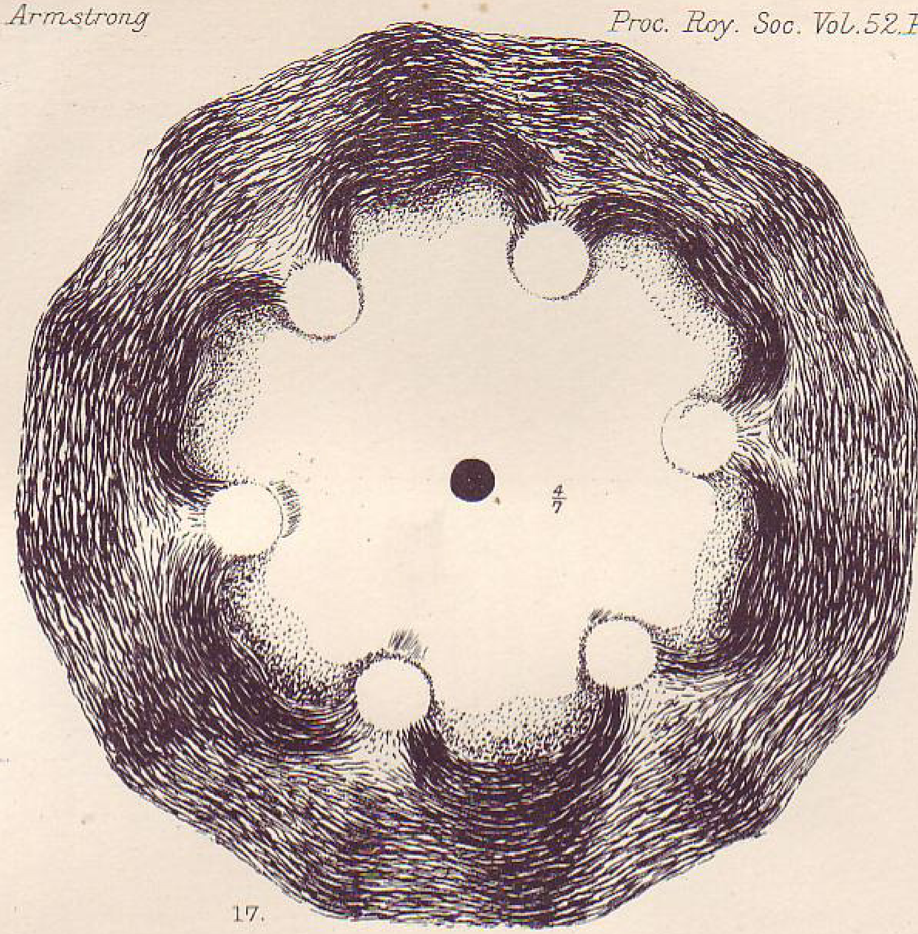

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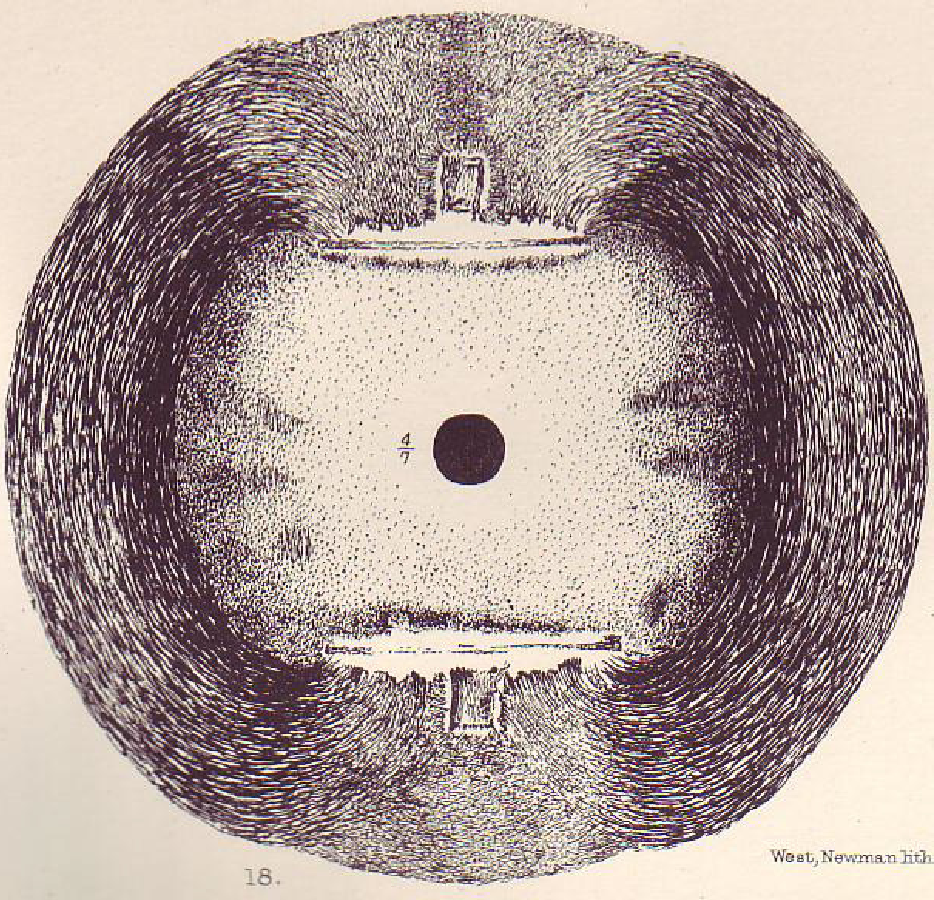

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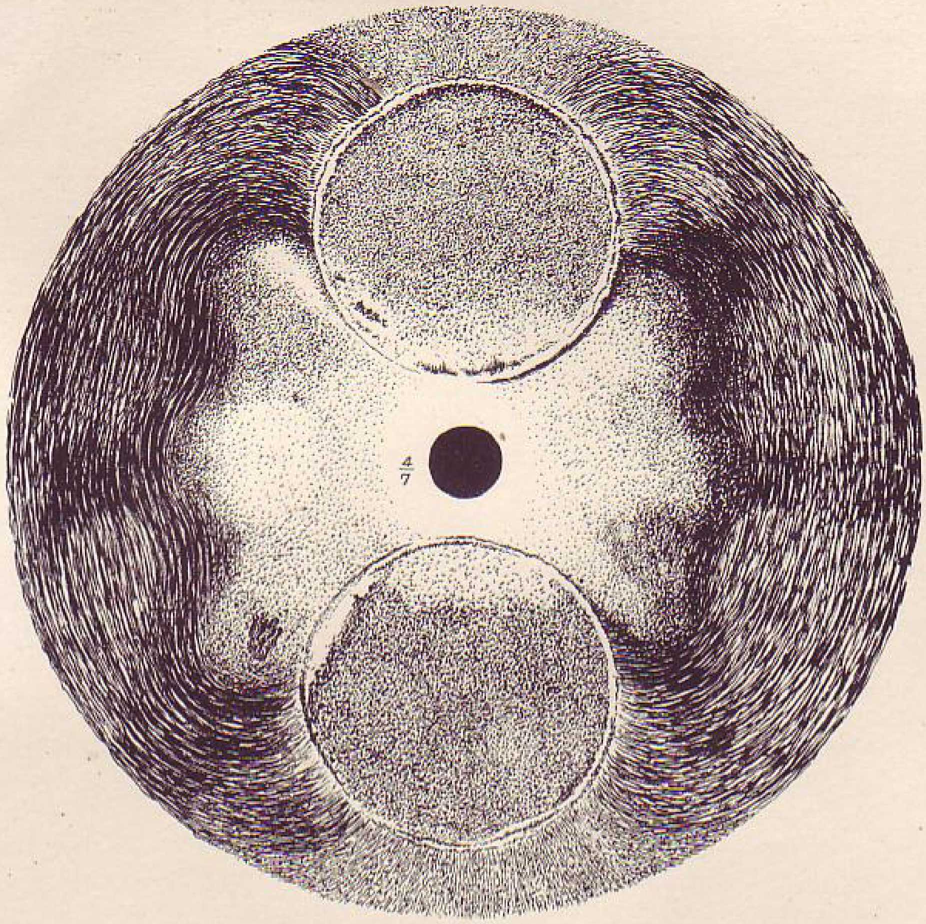

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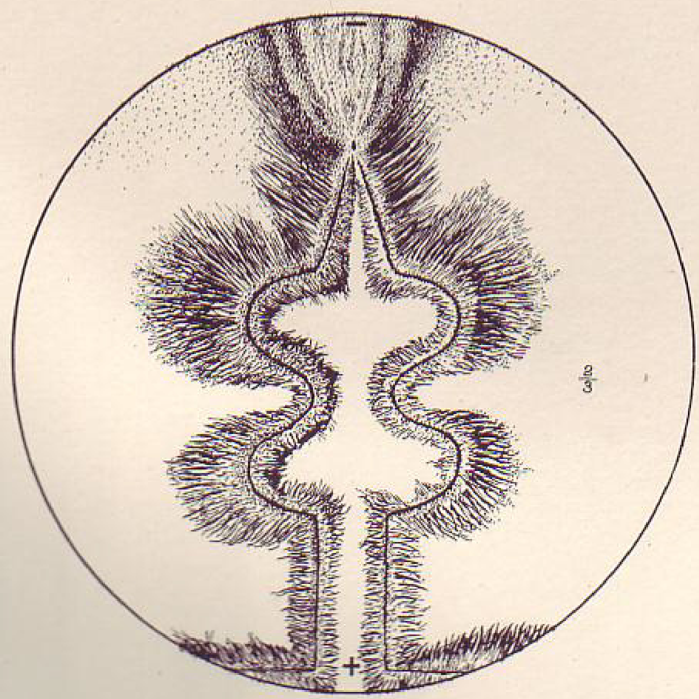

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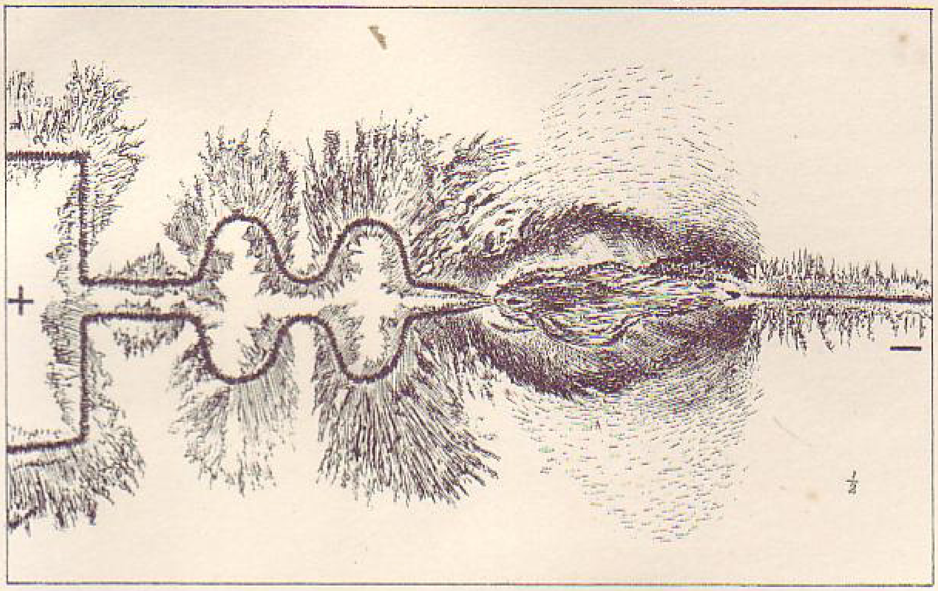

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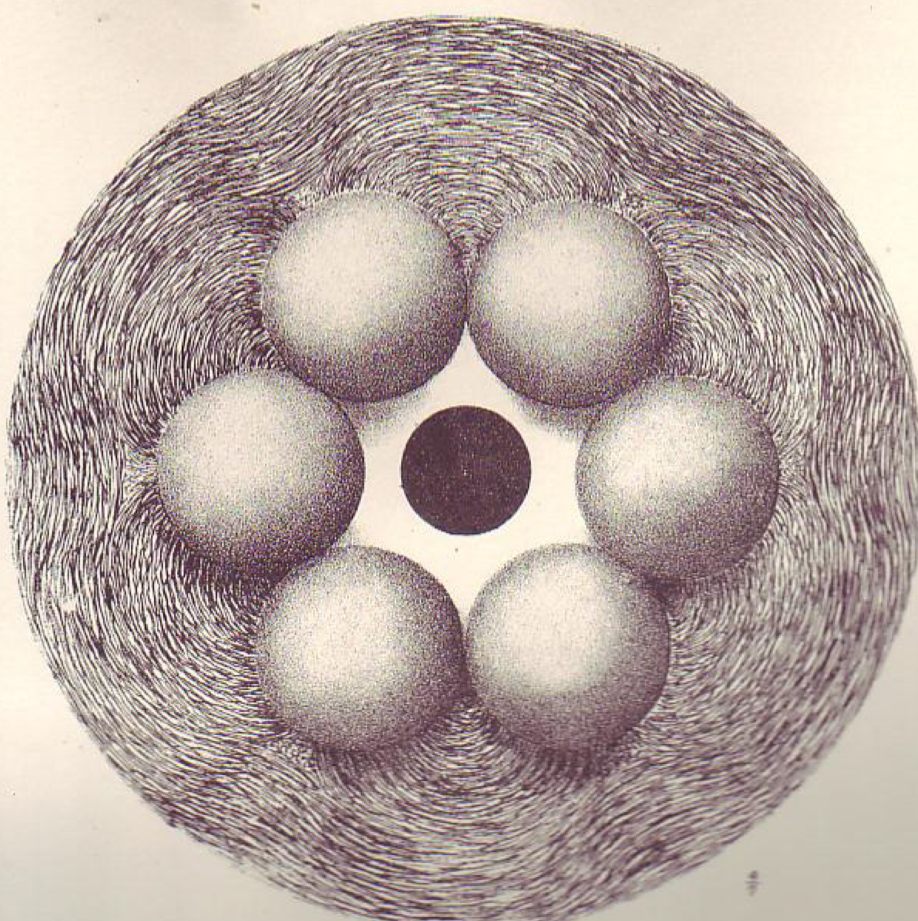

22.

West, Newman lith.

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